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Performance Evaluation of MMSE Based Multi Carrier-Code Division Multiple Access (MC-CDMA) Detector under Rayleigh and Rician Fading Channels

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Abstract: Multi-carrier is a fascinating choice for modern wireless communication system as it diminishes the issues of Inter Symbol Interference (ISI) and utilize frequency diversity. Minimum Mean Square Error (MMSE) Multi User Detection (MUD) technique is utilised for Multi Carrier-Code Division Multiple Access (MC-CDMA) which is a novel digital modulation technique under multipath fading environment. Multipath fading increases Bit Error Rate (BER) of a communication system due to which system performance degrades. MMSE algorithm is simulated in MATLAB and compares with different detections techniques such as Successive Interferences Cancellation (SIC), Parallel Interferences Cancellation (PIC), decorrelator and matched filter.

Key words: MC-CDMA, MMSE, MUD, Rayleigh and Rician fading, India

INTRODUCTION

The ever-expanding demand in wireless communication has impulse the growth of numerous signal processing and communication techniques to make fruitful of all resources. Multi Carrier-Code Division Multiple Access (MC-CDMA) technique has come to light as one of the optimistic future wireless communication technologies. Its development aimed at improving the performance over multipath links (Sung *et al*., 2015). The combination of Orthogonal Frequency Division Multiplexing (OFDM) and code Division Multiple Access (CDMA) techniques leads to what is called as Multi Carrier-Code Division Multiple Access (MC-CDMA) and it give the advantages of both the technologies. It offers high data rate, high spectral efficiency, multiple access capability, robustness to frequency selective fading and narrow band interference rejection among others (McCormick and Al-Susa, 2002). It has capability to reduce users signal power during transmission by making the use of spreading which helps users to communicate with low-level transmitted signal which is close to noise power level (Hara and Prasad 1997).

MC-CDMA generate a spreading code by converting original data into frequency domain by using different subcarriers as shown in Fig. 1. So, each user symbol is transmitted on different subcarrier thus achieving frequency diversity (Verma and Sakya, 2015) as shown in Fig. 2. In MC-CDMA with the help of the given spreading code the original data stream is spread and then different carrier is modulated with different chip, i.e., frequency domain spreading. User data stream is given as the input to serial to parallel converter so at the output of this symbol are transmitted on different subcarrier in parallel with much lower rate (Dhaliwal and Kaur, 2013; Sourour and Nakagawa, 1996).

The main advantage of MC-CDMA is that it is immune to fading because all subcarrier will not go into deep fade simultaneously as each user is divided among numerous frequency and different user will share same frequency band, so particular user will have a less chances to go into deep fade at same time (Hanzo *et al*., 2003). In wireless communication system, fading and multipath fading distorts the channel and also effect the Bit Error Rate (BER). Now a days there is an increasing demand for wireless communication so multiple user will share same communication resources due to which non-orthogonal multiplexing occurs. Due to non-orthogonal spreading codes Multi Access Interferences (MAI) took place. Ideally the cross-correlation between different users should be zero but because of non-orthogonal codes there will be some random values of cross correlation between different users. MAI is very much prone in MC-CDMA system due to multi-path fading which increase Bit Error Rate (BER) of the system (Sumala *et al*., 2007).

The signal which is transmitted from the transmitter antenna will reach at the receiver with a variety of paths. These varieties of paths are called as multi-path and wave

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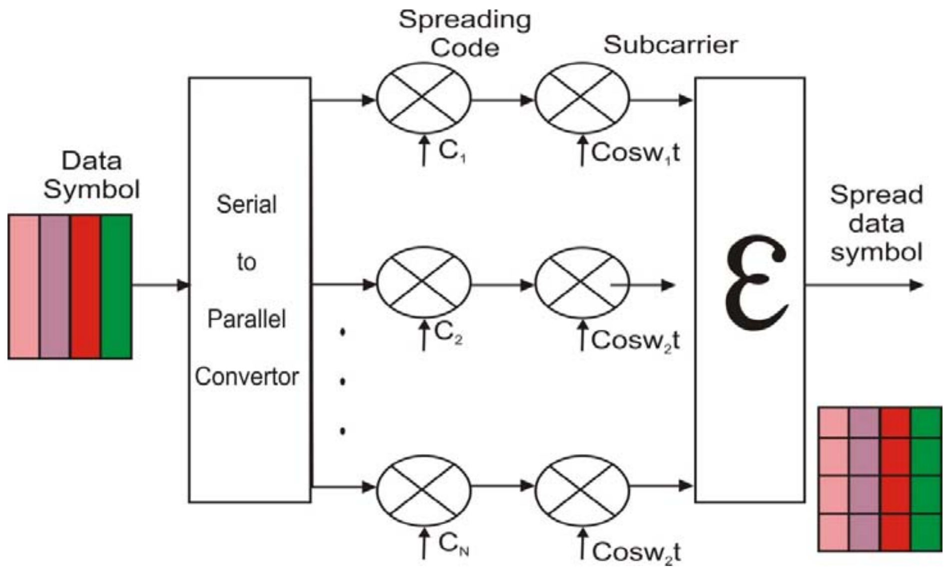

Fig. 1: MC-CDMA transmitter model

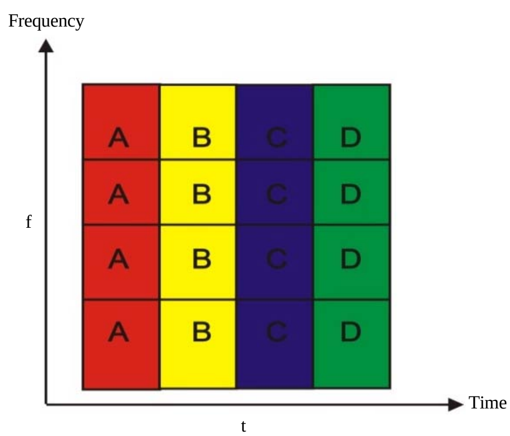

Fig. 2: Frequency diversity

is called as multi-path wave. So the received signal at the receiver is sum of entire multi-path wave. When main signal and the received signal will be in phase they will be added up and if out of phase will interfere with each other, signal strength will get reduced (Arfiya *et al*., 2015).

Moving transmitter receivers and stationary objects between the communication path results in a reflected surface which results in change in relative path length, because of this signal strength will vary and that will cause fading to take place. Fading belongs to the variation in the signal strength at the receiver when received. Fading can be of two types flat fading and selective fading. In flat fading all the frequencies are affected in a given channel either same or almost same. In selective fading, different frequencies in a given channel are affected to different degree. So, phase and amplitude will vary across the channel (Ekwe *et al*., 2014; Sadeque *et al*., 2015). There are different fading model that are used to estimate the fading over a channel for example, Nakagami fading, Weibull fading, Log-normal shadow fading, Rayleigh and Rician fading.

Rayleigh and Rician fading Models are most commonly used to estimate the fading over a multipath channel. Rayleigh fading is considered when there is presence of multiple indirect paths between transmitter and receiver and no direct line of sight path between them. As there is no dominant component, it represents a worst scenario (Li *et al*., 2009) Rician fading occur when there is presence of line of sight component. Its amplitude gain is given by Rician distribution. Rayleigh fading is a special case of Rician fading. With the absence of line of sight component in Rician, Rician fading will be same as Rayleigh fading (Xiao *et al*., 2006).

Multiuser detection is a best tool to combat multipath fading. Single user detection technique is not resistant to MAI and to near far problems so generally Multi user detection technique is used to mitigate it. In this study, MC-CDMA signals are detected using MMSE based Multi User Detection over multipath fading channel. Rayleigh and Rician fading model are investigated with our proposed detector. On the basis of numerical results MMSE based detector is compared with Successive Interferences Cancellation (SIC) Parallel Interferences Cancellation (PIC) De-correlator and Matched filter in multipath fading environment.

MATERIALS AND METHODS

Rayleigh and rician fading channel: Multi path reception is the main cause of Rayleigh fading. In multipath fading channel delays related to the variety of the signals path changes in an unpredictable way. When there are a large number of paths, the central limit theorem can be applied to model the time variant impulse responses of the channel as a complex valued gaussian random process. The Rayleigh fading channel of the transmitted signal x(t) has a multiplicative distortion h(t) and noise n(t), it is given as y(t) = h(t)x(t)+n(t). Where y(t) is the waveform that had been received. It is considered as a cost efficient model for tropospheric and ionospheric signal propagation as in this no direct line of sight component is required. The envelope of Rayleigh fading is given as Rayleigh distribution (Xiao *et al.*, 2006). The Rayleigh probability density function is given as:

$$p(r)=\left(\frac{r}{\sigma^2}\exp\left(-\frac{r}{2\sigma^2}\right)\right)\text{for } r>0 \quad (1)$$

Where:

σ = Rms value of received signal

σ^2 = Time average power at the envelope detector, respectively

Rayleigh fading is a small scale effect. This fading is super imposed on the properties of environment like path loss and shadowing. It can be used in urban areas where there is no line of sight communications is possible due to many buildings and objects that attenuate, reflect, diffract or refract the signals.

For radio propagation Rician fading model is considered as stochastic model. This kind of fading occurs when a line of sight paths is present and signal is much stronger than other. Its amplitude gain is stated by Rician distribution. The Rician probability density function is expressed as:

$$p(r)=\left(\frac{r}{\sigma^2}\exp\left(-\frac{r^2+A^2}{2\sigma^2}\right)1_0\left(\frac{A_r}{\sigma^2}\right)\right) \quad (2)$$

$$\text{with } r\geq 0,\ A\geq 0$$

Where:

A = Amplitude of sightline signal

$1_0(Y)$ = Altered first kind with zero order bessel function

Rician fading can be related to two terms 1 K and Ω. K is a defined as a ratio of power in the line of sight path to the power in all other direction Ω is defined as the total power from the directed and all other scattered path.

MMSE multi user detection: Conventional matched filter is also known as Single User Detection (SUD). This is very ease to implement. In this MAI is not considered and treated as a noise. In this we apply a bank of matched filter and threshold devices to detect the bit received correctly. In this all user will be demodulated independently and do not require the estimation about user amplitude and channel. There are many drawback of SUD as it cannot eliminate MAI and also it is not resistant to near-far effect so there is also non-zero probability of error even with a presence of zero noise. SUD cannot be used for practical purpose (Poor and Verdu, 1998; Hanzo, 1998). Hence, MUD is best procedure to enhance the detection of each individual user developed by Verdu (1980) where information about multiple users is used. In this MAI is treated as a useful term and processing of the interferences term is carried out to decode the bit correctly (Duel-Hallen *et al.*, 1995).

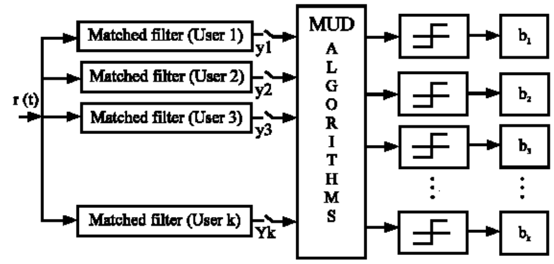

Fig. 3: Multi user detection

MUD is classified as Optimum and sub-optimum detector. Optimum MUD is based on maximum-likelihood detection. It means if there are K number of users, then optimum MUD will require 2^k number of calculations. The main drawback of this system is that it is very complex and not preferred when large number of users are present. So this detector is not used for practical implementation. Sub-optimum detector is again classified into two groups linear and non-linear detector (Fig. 3).

Linear detector is of two types decorrelator and MMSE. In decorrelator the inverse of cross-correlation matrix (R) at the output of matched filter is applied to decouple the data properly. The main problem with these techniques is that it often results in unacceptable enhancement of the background noise (Kumar and Saxena, 2015). Non-linear detector is of two types Successive Interferences Cancellation (SIC) and Parallel Interferences Cancellation (PIC). The basic principle behind SIC is that it serially cancel the interferences of the user from the output of matched filter to decrease the power level. The major problem is delay or latency problem which increases as the number of stages goes on increasing (Chauhan *et al.*, 2015). In PIC, the estimate of user's interferences is cancelled out at the output of the matched filter in a parallel manner. It is a multistage process. PIC is faster as compared to SIC but it requires perfect initial amplitude estimation under equal power

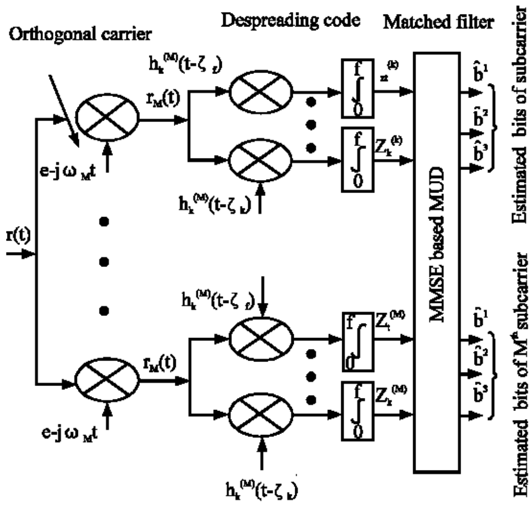

Fig. 4: MMSE MUD for MC-CDMA system

control condition, PIC works better than SIC. The drawback of PIC is that in unequal power condition the performance of PIC degrades (Wu *et al*., 2015).

In MMSE, the output of the matched filter bank is Y = RAb+n. From this equation it is clear that output of the matched filter depend on cross-correlation matrix, transmitted bits and noise (Halunga and Vizireanu, 2010). The output of the matched filter bank, i.e., Y are passed through MMSE detector and it is multiplied by the $(R+\sigma^2A^{-2})^{-1}$ to decouple the data properly. It eliminates the background noise, MAI and reduces near-far problem (Miller and Rainbolt, 2000). There is M number of subscribers among which the received composite signal is divided as shown in Fig. 4. Every user's small part of data is carried by the subscriber f_1 which is then spread by the spreading code h_1, i.e., 1st chip. Similarly, the spread sequences S_1-S_K code the entire signal from subcarrier f_1 to f_M. The received signal on the subcarrier is given as:

$$r_{m(t)} = \sum_{K=1}^{K}\left[A_k b_k(t) s_{k,m}(t)\right] + n(t) \quad (3)$$

Where:

- A_k = Kth user amplitude (k = 1, ..., K)
- M = Total number of sub-carriers
- $b_k(t)$ = Transmitted bit of Kth user's
- $S_{k,m}(t)$ = Spreading sequences of the Kth user's Mth for the subcarrier
- n(t) = Additive white Gaussian Noise (AWGN)
- ω = $2\pi f_M$
- f_M = (1, 2, ..., M) are the subcarrier frequency

For Mth subcarrier the output of the matched filter can be shown in a matrix form:

$$Y = RAb + n \quad (4)$$

Where:

- R = Cross-correlation matrix
- A = Amplitude matrix (A = diag $A_1, A_2, ..., n_k)^T$)
- b = bit matrix (b = $(b_1, b_2, ..., b_k)^T$)
- n = AWGN noise matrix (n = $(n_1, n_2, ..., n_k)^T$)

Equation 4 can be moreover noted as:

$$\hat{b}_k = \text{sgn}\left\{\frac{1}{A_k}\left(\left[R+\sigma^2A^{-2}\right]^{-1} Y_k\right)\right\} = \text{sgn}\left(\left(\left[R+\sigma^2A^{-2}\right]^{-1} Y\right)k\right) \quad (5)$$

Equation 4 observes the data bit b_k enlarging this objective statement. User data bit vector for K number of users is tabbed which stretch this objective function.

RESULTS AND DISCUSSION

For the simulation design, it has been considered that channel is AWGN, 16 numbers of users are taken and gold sequences of 31 bits have been used as a spreading code. List of parameters have been considered for estimating the performance of MC-CDMA system:

- Number of subcarriers: 31
- Independent multipath fading occurred with every subcarrier due to its asynchronous nature
- It is assumed that there is perfect subcarrier synchronization with no frequency offset
- Non-linear distortion is assumed to be zero
- Quadrature Phase Shift Keying (QPSK) modulation is used

First of all performances of QPSK modulation and demodulation is observed under AWGN and Rayleigh fading channel. For this simulation 10.000 bits are modulated and demodulated.

Figure 5 shows the effect of Signal to Noise Ratio (SNR) on constellation diagram of QPSK. It is observed that with the increase of SNR, QPSK symbols become more distinguishable and Bit Error Rate (BER) decreases. It can be seen in Fig. 5a where Constellation of received symbols is drawn for SNR = 5.0103dB, symbols are not distinguishable because of very high bit error rate. Graph is drawn between theoretical AWGN Rayleigh and simulated AWGN Rayleigh channel which is shown in Fig. 6. It is observed that BER increases under Rayleigh fading channel.

Now, we have already observed the effect of fading channel on the BER for QPSK modulation. Now, we will observe the performances of MMSE Multi User Detection

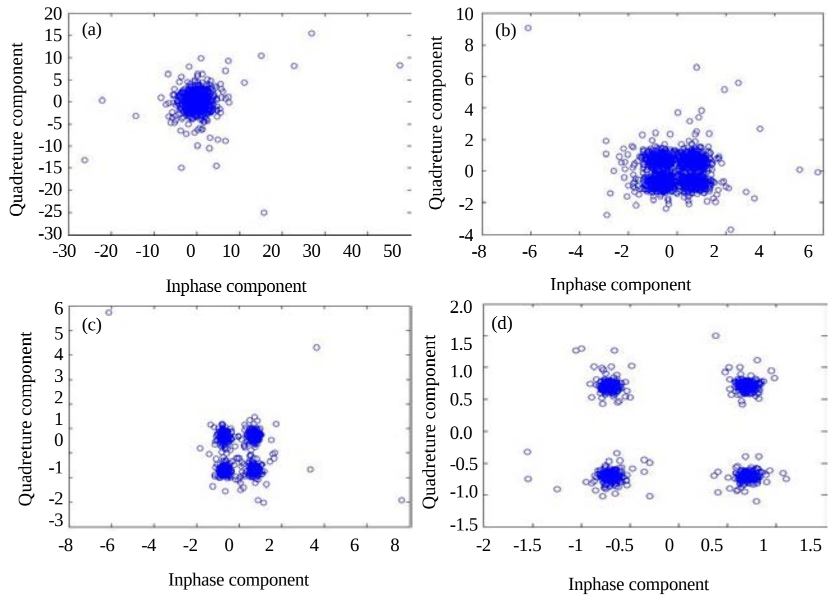

Fig. 5: Constellation of received symbol: a) SNR = 5.0103; b) SNR = 15.0103; c) SNR = 25.0103 and d) SNR = 33.0103

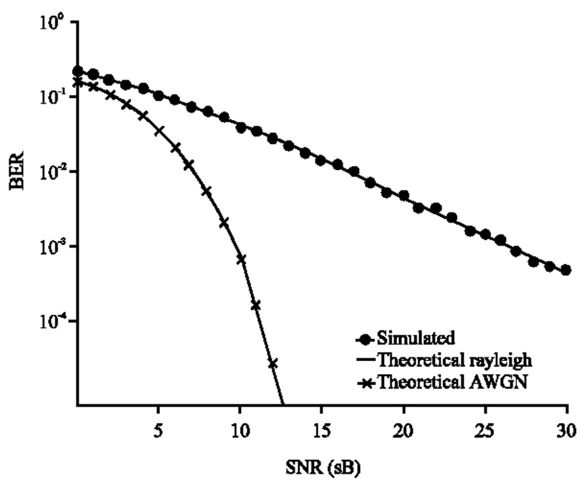

Fig. 6: QPSK modulations in finding channel

under various spreading codes (orthogonal codes, i.e., gold code, kasami code and walsh code). It is observed from Fig. 7 that MMSE MUD performs well when gold codes are used as spreading codes. Gold codes give minimum BER due to their better cross correlation and auto correlation properties.

BER performances: In the simulation transmitted bits are 10,000 bits per user and these bits have been detected by different multiuser detector. A graph is plotted between different values of Signal to Noise Ratio (SNR) E_b/N_O and different values of BER. For simulation purpose two different cases are chosen.

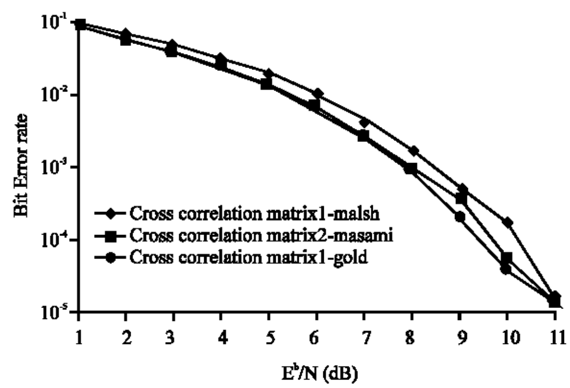

Fig. 7: Cross-correlation of spreading code

Case 1: equal power scenario: In this case, multipaths fading, i.e. (Rayleigh and Rician fading) have been investigated for equal power scenario where it is assumed that all the users are received with equal power at the detector end. It can be observed from Fig. 7 that MMSE based MC-CDMA detector is capable of mitigating the MAI and multipath fading to a great extent. It can be seen from Fig. 8 and 9 that performances of SIC based MC-CDMA detector are best but SIC detector cannot be employed from practical implementation because of latency problem.

Table 1 shows BER performances of MMSE based MC-CDMA detector in two scenario, i.e., equal power and near far effect for 14 bits. It is observed that for equal power scenario BER performances of Rician fading is slightly better than Rayleigh fading. It is due to the presence of Line Of Sight (LOS) path in Rician fading.

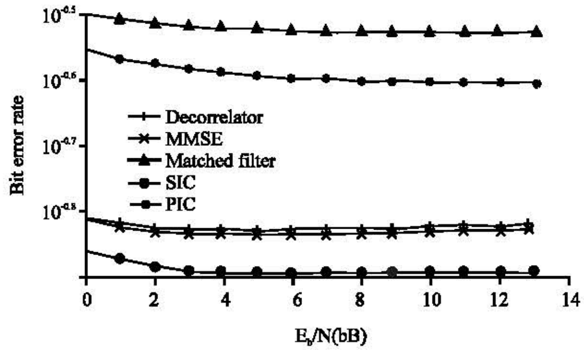

Fig. 8: Rayleigh fading

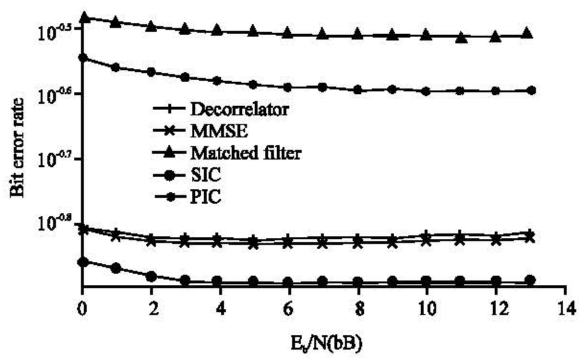

Fig. 9: Rician fading

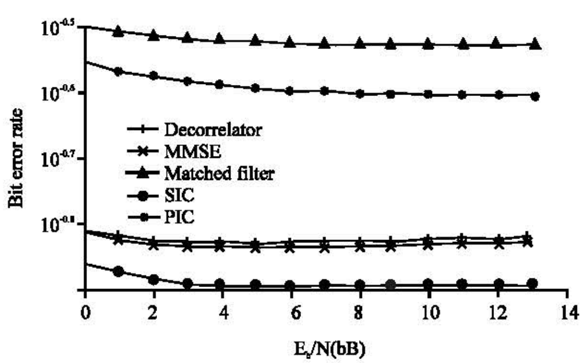

Fig. 10: Rayleigh fading in near far effect

Case 2 (near far effect): In this case users are assumed to be received with unequal power by different MC-CDMA detector. It can be observed from Fig. 10 and 11 that except MMSE, SIC based detector, BER performances of all the detector get degrades because of variation in power level of the users. As shown in figures BER performances of MMSE and SIC improves in the presences of near-far effect. It can be seen from Table 1 that under near-far effect performance of MMSE based MC-CDMA detector is nearly similar to when user are received with equal power. This result confirms that

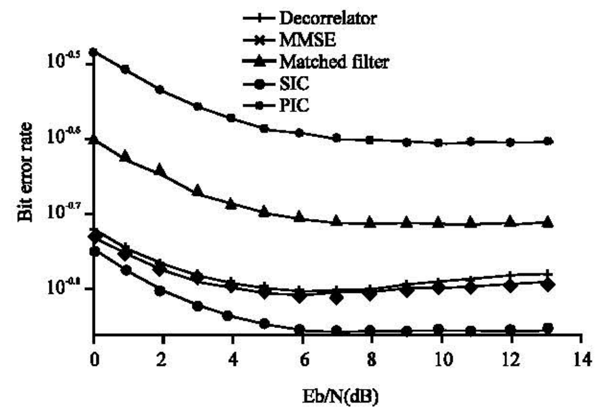

Fig. 11: Rician fading in near far effect

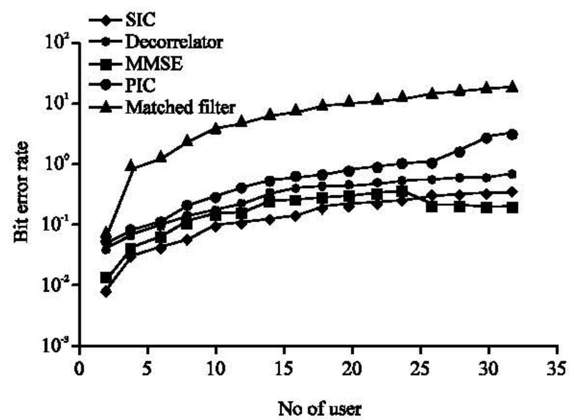

Fig. 12: BER performances for different no of users

Table 1: BER performances of MMSE based MC-CDMA detector in 2 scenarios for 14 bits

Equal power condition		Near-far condition	
Rayleigh fading	Rician fading	Rayleigh fading	Rician fading
0.1793	0.1791	0.1565	0.1560
01686	0.1680	0.1538	0.1531
0.1596	0.1592	0.1520	0.1514
0.1536	0.1527	0.1517	0.1510
0.1496	0.1493	0.1508	0.1503
0.1475	0.1470	0.1509	0.1500
0.1472	0.1468	0.1510	0.1503
0.1477	0.1471	0.1511	0.1503
0.1488	0.1480	0.1517	0.1503
0.1499	0.1493	0.1520	0.1508
0.1514	0.1514	0.1524	0.1512
0.1522	0.1521	0.1528	0.1513
0.1533	0.1532	0.1531	0.1516
0.1536	0.1536	0.1535	0.1519

MMSE based MC-CDMA detector is an effective detector under an asynchronous multipath fading environments.

System capacity: Figure 12 describes BER performances of all the detectors with different no of users. It is seen that with an increase in number of users BER of all detector increases. It can be seen that from lesser number of users performances of SIC is better than MMSE but with a increase number of users beyond 25 the BER performances of MMSE get decreased and that of SIC get increase. It can be concluded that MMSE based detector can accommodate a large number of users without increasing BER. So in terms of system capacity MMSE performances is better than all other detector.

CONCLUSION

In this study, MMSE based MC-CDMA detector has been investigated under multi-path fading environments Performances of this detector is also analysed for different spreading code (orthogonal code). Further, this detector is also investigated for both Rayleigh and Rician fading. Numerical results show that MMSE based MC-CDMA detector gives optimum results under multipath and near-far environment. It has also been observed that system capacity of this detector is better than all other detector.

RECOMMENDATIONS

MMSE based MC-CDMA detector could also be investigated for other model of multi-path fading such as Nakagami fading, Weibull fading, Log-normal shadow fading. MMSE based MC-CDMA detector could also be modulated with the help of other modulation technique like Bipolar Phase Shift Keying (BPSK), Quadrature Amplitude Modulation (QAM), etc.

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